black carbon

from combustion source to radiative impact
...where are the biggest uncertainties?

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Black Carbon Emissions & Climate Change

San Diego, California

acknowledgements - thanks

- Workshop organizers! for invitation & focus
- Collaborators

  Haolin Sun, UIUC; Bob Bergstrom, NASA-Ames; David Covert, U Washington; David Streets, Argonne Nat'l Labs; Trish Quinn & Tim Bates, NOAA-PMEL; Phil Rasch, NCAR

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  - U.S. EPA: STAR grant; Climate office
  - NASA: ACMAP & EOS
- Offsets for travel CO_2
  - travel.500ppm.com

outline

1. a Trail, 2 Hypotheses, and a (re)Definition
2. Inventories
3. Global models, *a very little*
4. Climate-relevant properties
5. finale: Tami's Top 4

the Trail (beset by Alligators)

Action

Emission

atmospheric Concentration

first-round Impact

climate Response

life-system Impact

"Emission Factor"

"Lifetime"

"Normalized Forcing"

(need metric for clouds, etc too!)

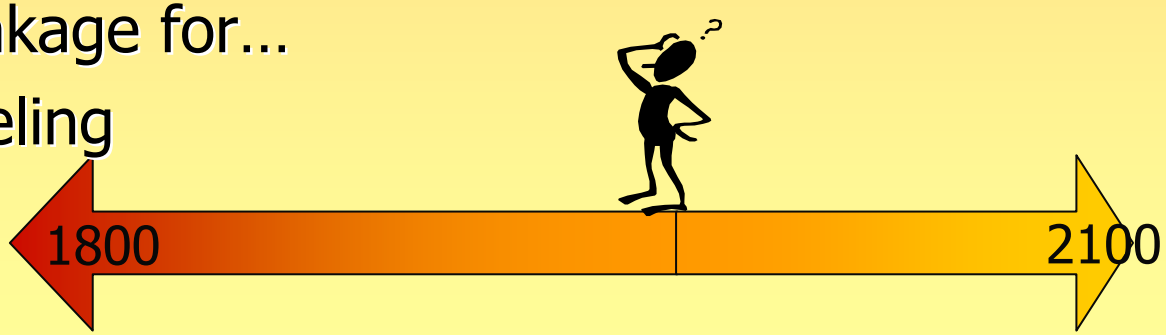
"Sensitivity/Efficacy"

hypothesis I

the purpose of climate modeling
is to go where measurements cannot:

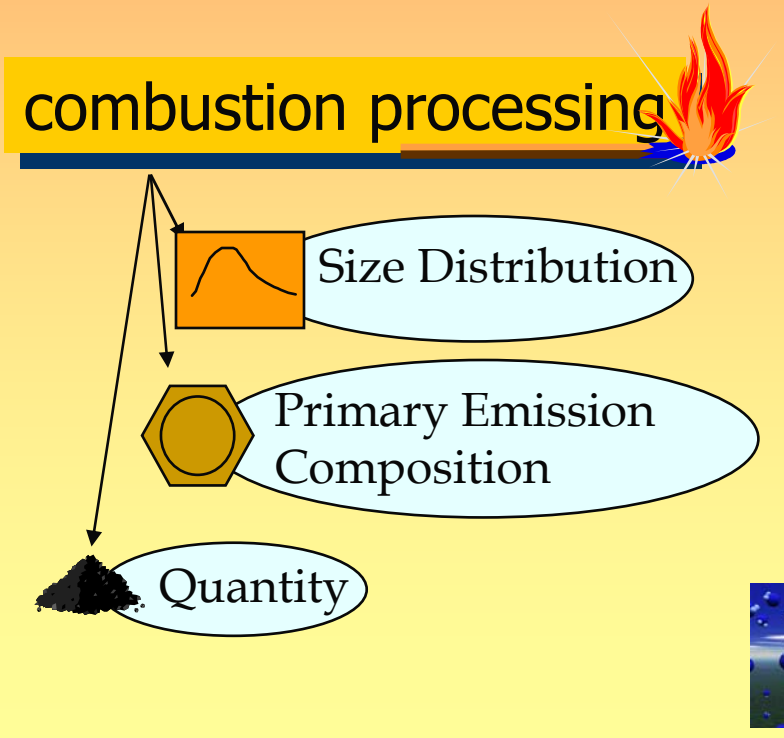
the past, the hypothetical future,
the big (global) and little (microphysical) pictures

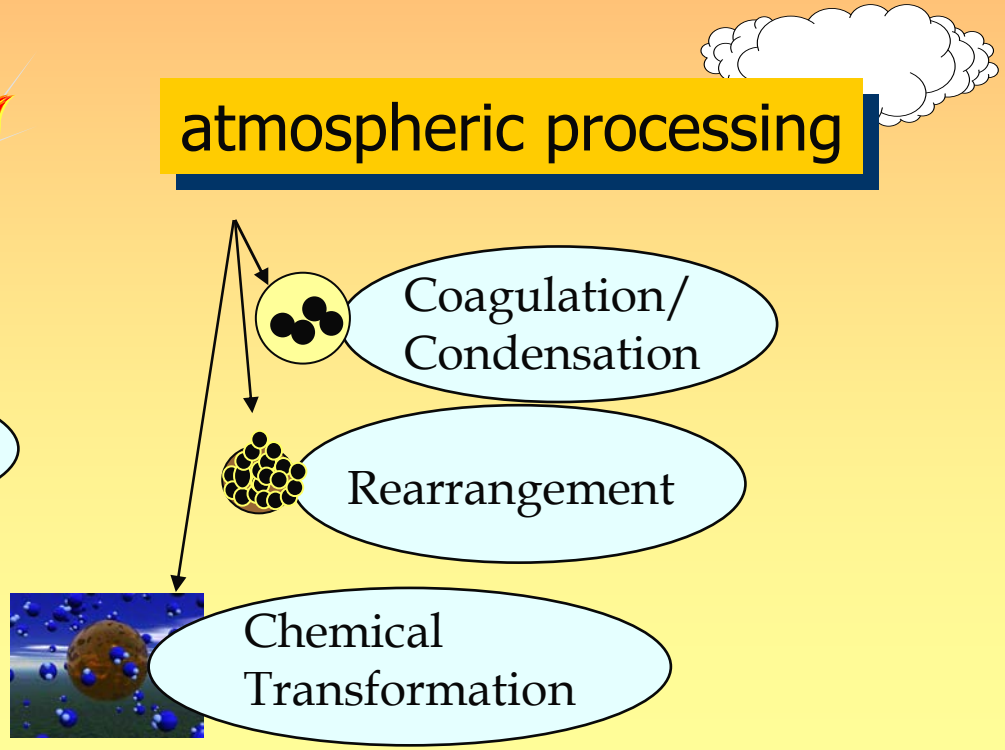
- OK for assessment of present:
  - generalized emissions (no explicit action linkage)
  - observationally-based forcing only
- need more direct linkage for…
  - past/future modeling



hypothesis II

two distinctly different environments
influence the properties that govern
aerosol-climate interaction





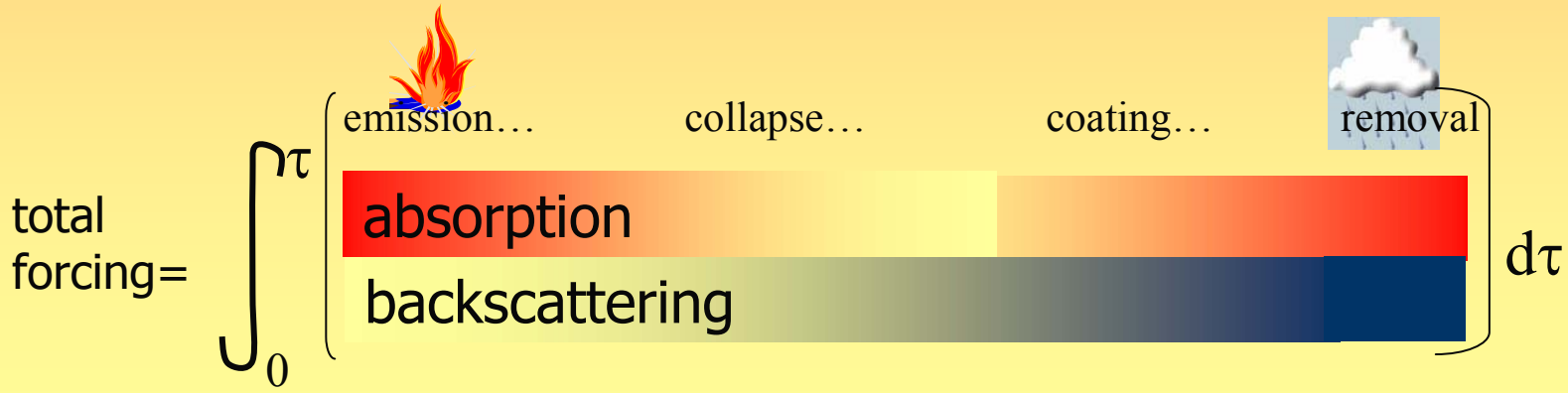
definition: emission inventory

the expanded concept:

a tabulation of particle quantities and properties governed by the "combustion domain"

source-dependent, climate-relevant characteristics

our goal: estimate total impact of technology change



global inventories: "Bond/Streets"

BC emission = fuel use x PM emission factor x characteristics

- activity levels (usually *fuel*)
  - International Energy Agency, United Nations, etc.
- technology divisions
  - division into >100 fuel+technology categories
  - regionally-distinct technology divisions
- emission factors (PM x BC fraction)
- gridding
  - by population, land use, fire counts
- management: SPEW (Speciated Pollutant Emission Wizard)
  - relational database (~40 descriptive linked databases)

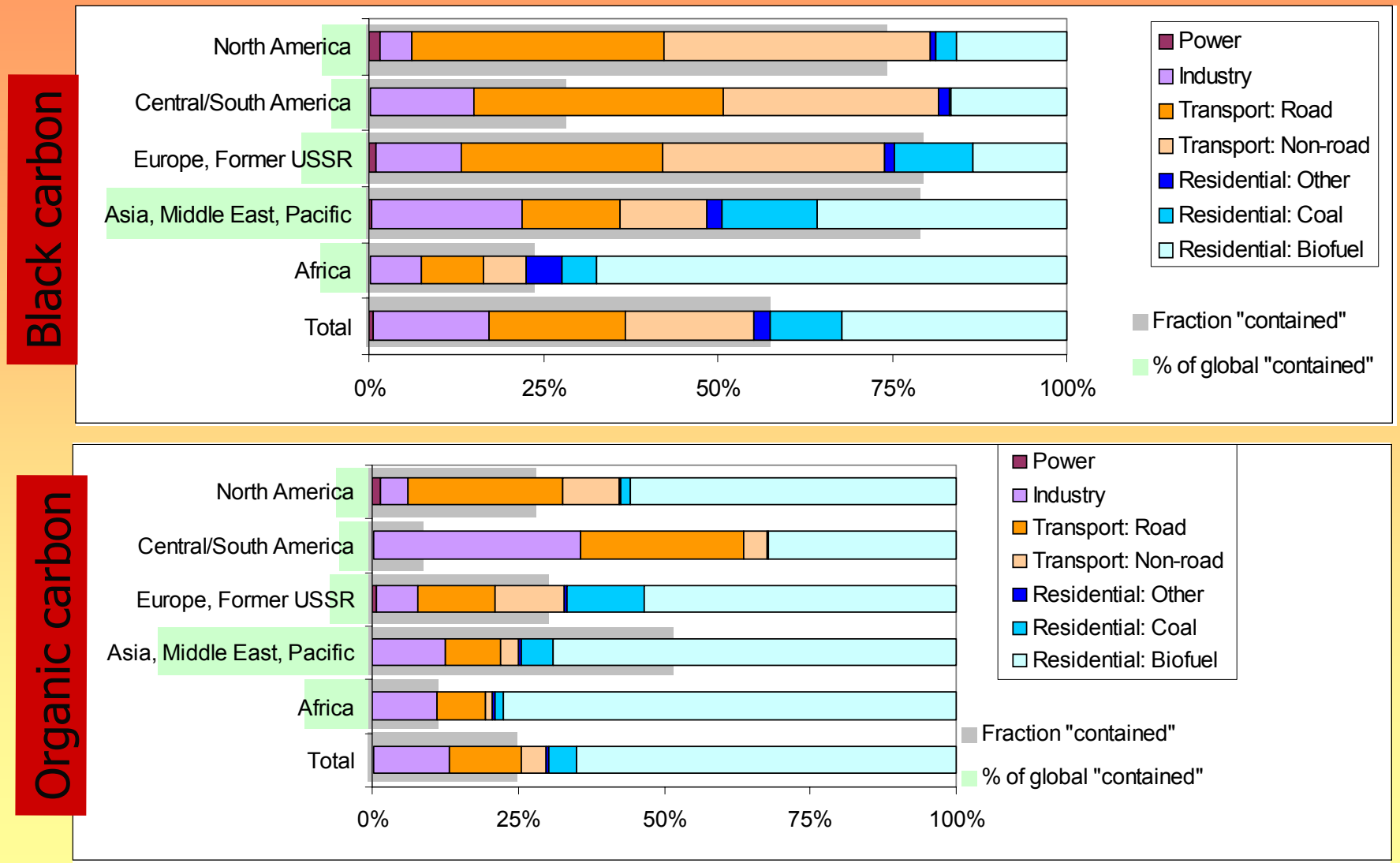
perturbations: China-BC (2001), TRACE-P (2003), future (2004) & past (in progress) estimates

global inventories: *state of the science*

- spatial resolution: 1ºx 1º
  - sub-grid processes must be represented separately (and usually aren't)
- aerosol composition: minimal
  - last IPCC: OC=4xBC for fossil fuel
  - new: activity-specific OC+BC
- aerosol physical state: rudimentary
  - most: old/unsupportable values for size/optics

global sources

Bond, Streets et al., JGR 109, D14203, doi:10.1029/2003JD003697



transport sector treatment

- on-road
  - estimated fleet emission factor: age distribution for U.S./Europe
  - superemitters
- off-road mobile/industrial
  - estimates by Kean et al. (2000)
  - need updates w/current measurements
- non-road transport
  - EPA documents (memos)
- "real world" factor?
  - not yet included

Image: www.nada.org

some "corrections" to earlier work

Bond (2004) vs Cooke (1999)

Differences are easily explained.

Sam Cooke | James Bond

Coal, power generation (difference 1.5 Tg/yr)

We rely on measured BC fractions (<1%) instead of guesses (25%)

On-road diesel (difference 1 Tg/yr)

We use emission measurements and World Bank studies instead of assuming "developing countries have 5x higher emissions" (15 g/kg average PM emission factor)

Domestic diesel (difference 0.25 Tg/yr; large in Europe)

We do not apply emission factors for internal combustion engines to external-combustion boilers

present dilemma

- "corrections" reduced emission estimates from 14 Tg/yr to 8 Tg/yr
- models typically need more BC to match observations… not less!

Need help from *you*! ("Real-world", source apportionment…)

"What are the limits in our ability to measure freshly emitted and ambient BC?"

By most accounts, either thermally- or optically- measured BC is uncertain by a factor of 2.

This uncertainty affects our ability to corroborate emission-based global transport models by using ambient measurements.

uncertainties

- inventory contains full uncertainty propagation (activity estimates, emission factors, etc)
- of course, there are many guesses

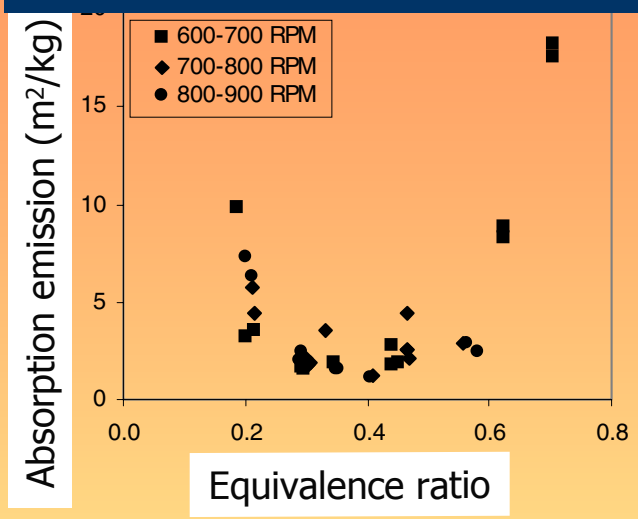
Sector	N.America BC	N.America OC	S/C America BC	S/C America OC	Europe BC	Europe OC	Former USSR BC	Former USSR OC	Asia BC	Asia OC	Africa BC	Africa OC
Contained combustion												
Agri waste/residential												
Anim waste/residential												
Coal/industrial												
Diesel/off-road												
Coal/cokemaking												
Coal/residential												
Diesel/on-road												
Diesel/residential												
Gasoline/transport												
Wood/charcoal prod												
Wood/industrial												
Wood/residential												

Uncertainty > 25% of total "contained combustion" emission estimate *for region*

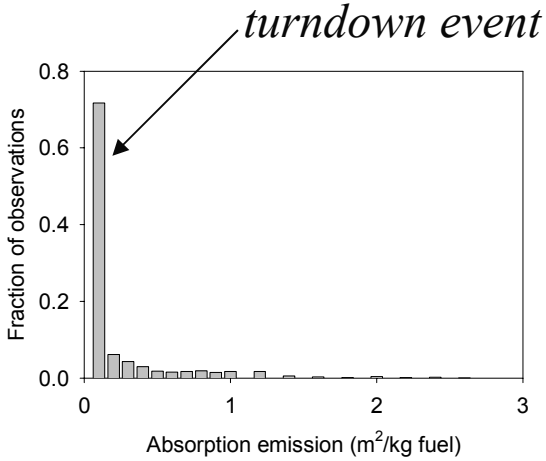
Uncertainty > 10%

single-source variability

indirect-injection diesel engine



industrial oil boiler



"What are the limits in our ability to predict the mass of BC emissions from individual source types?"

Many of our sectoral emission estimates are uncertain by a factor of ~2.There is wide variability in both within-source and between-source variation.

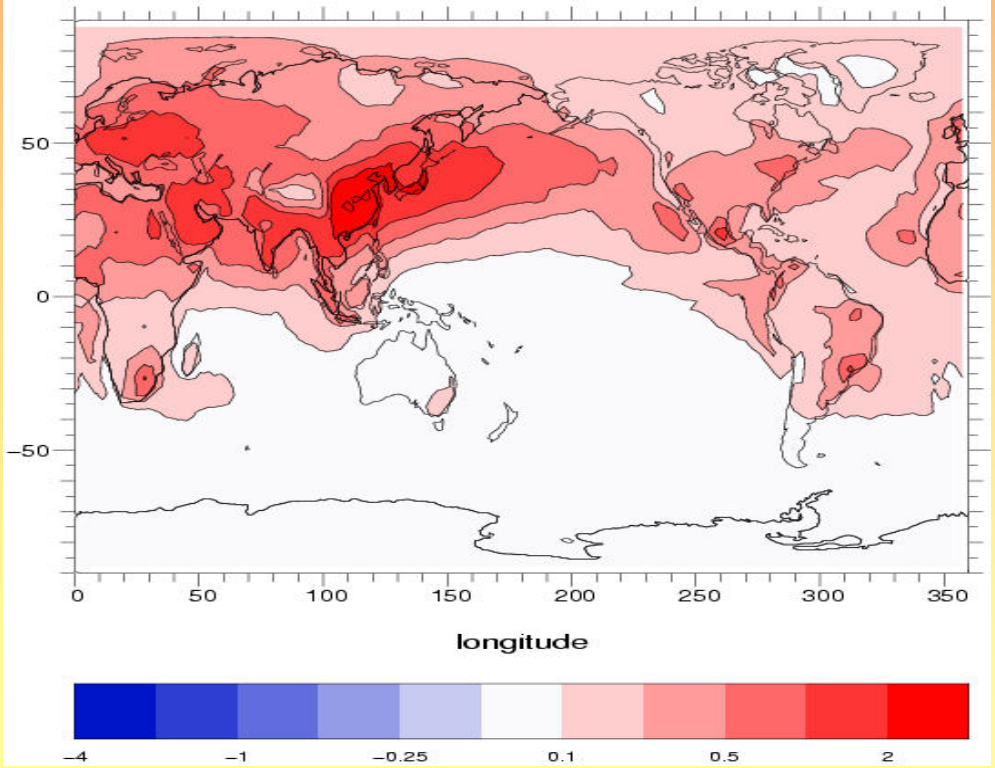
Note: diesel work is excellent forum for examining variability issues & developing approaches!

emission uncertainty→ forcing

graph & table represent spatially-dependent forcing uncertainty due to uncertainty in *fossil-fuel emissions* only

Model: NCAR-MATCH with 2001 NCEP-reanalysis met data

BC forcing: high case minus central case (W/m^2)



TOA Forcing Summary

	BC	OC
Low	+0.26	-0.21
Central	+0.37	-0.22
High	+0.65	-0.25
Prev 84	+0.40	-0.23

model intercomparison

why do direct forcing results differ?

black carbon

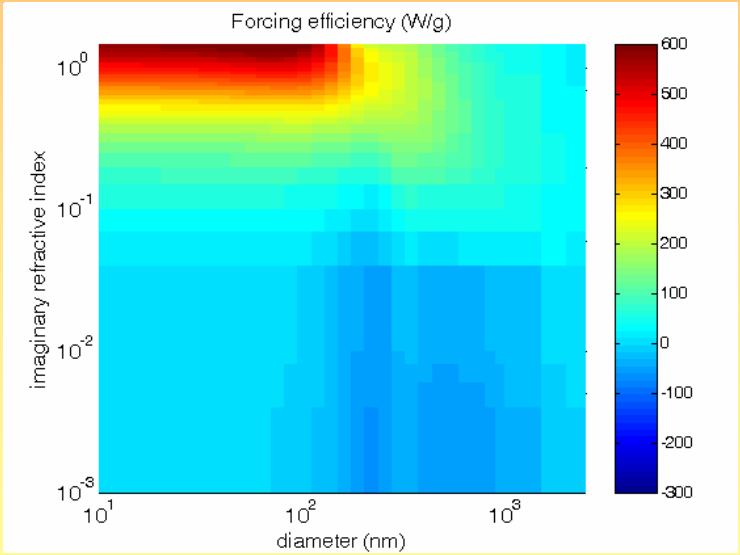
Chung, Haywood, Jacobson, Koch, Myhre, Penner, Wang

- lifetime
- optical assumptions
- vertical location

better resolved than OC:
- normalize by lifetime & optics
- TOA forcing estimates vary by 20%

organic carbon

- lifetime
- optical properties (absorp by OC) → *factor-2*
- water uptake ("f-RH") → *factor-2*



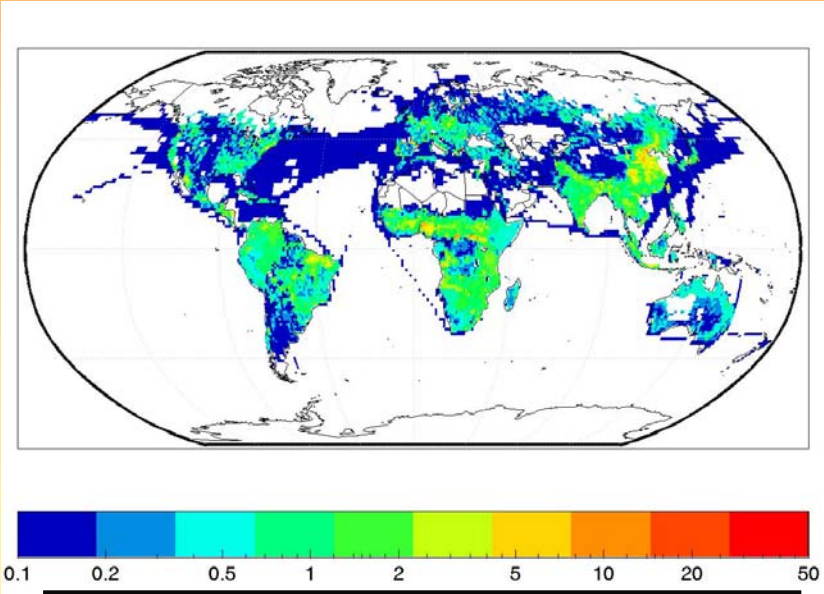
accounting for OC properties

Haolin Sun, UIUC

- "OC" is dead; long live OC
- Climate-relevant, technology-specific OC divisions

CROSS1-OC
Climate
Relevant
Optical &
Structural
Subgroups
(ver 1) of **OC**

4 groups, tractable for climate models (we hope)

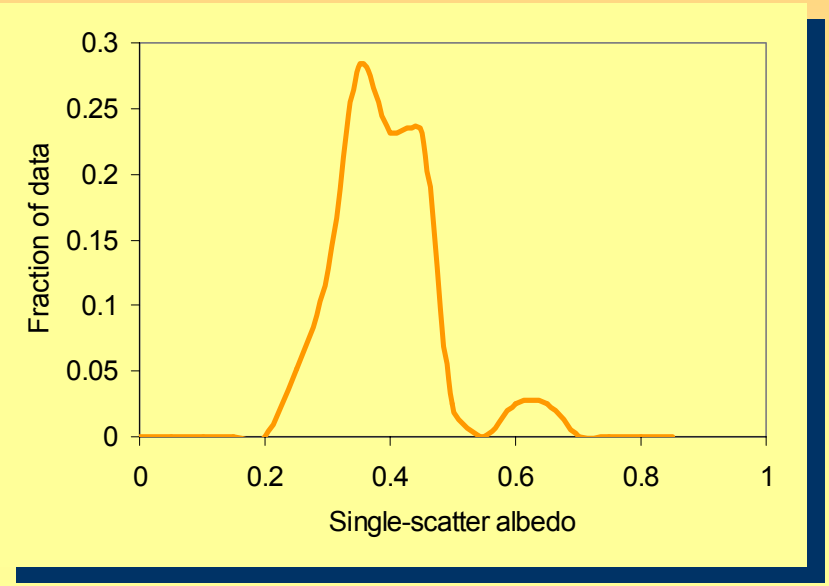


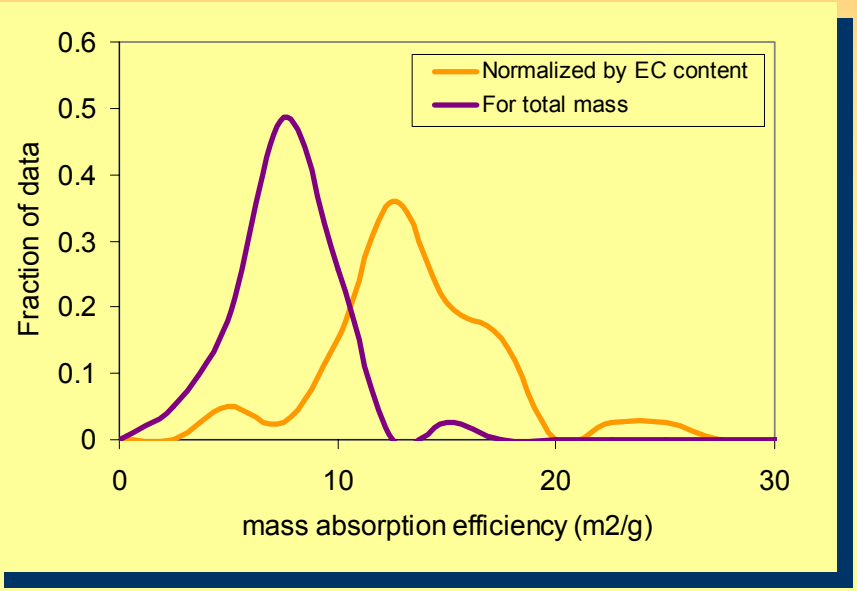
Example:
Emissions of WIOC-SA ng/m²/sec

climate-relevant source "profiles" (I)

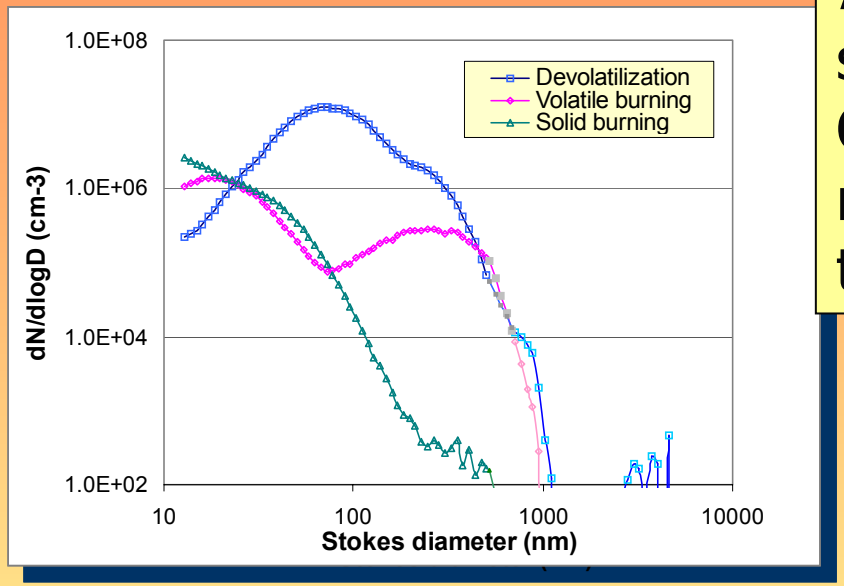
- we can *usually* measure size
  - need relationships for mobility of fractal particles
- ability to measure *relevant* composition needs work
  - light-absorbing component; other properties

Results of solid-fuel source tests





source "profiles" (II)



measured
size (SMPS/APS)
OC/EC
major ions
trace metals

"closure"
still
difficult

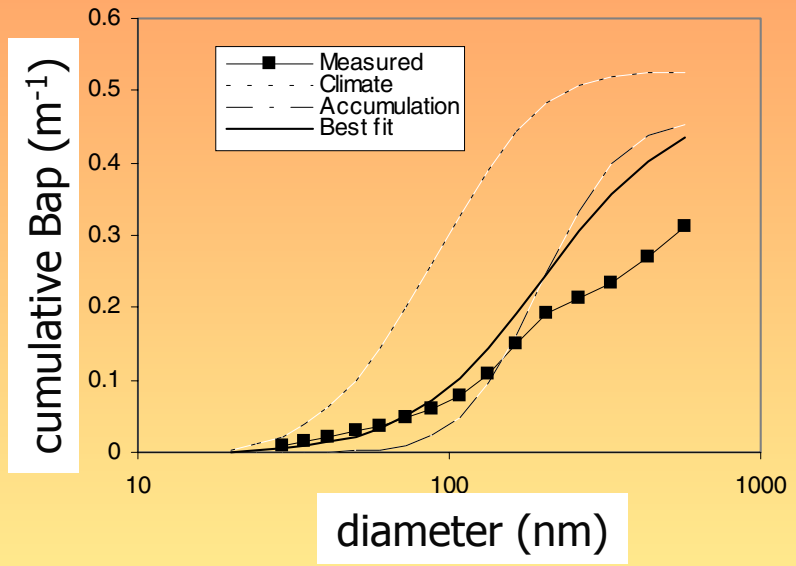
measured
absorption
scattering

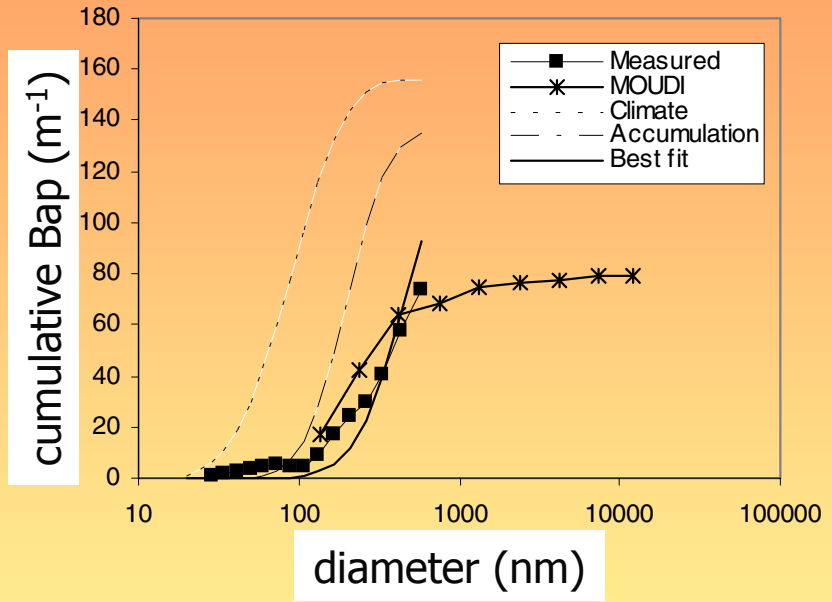
"What are the limits in our ability to measure freshly emitted and ambient BC?"

Because thermally-measured EC is uncertain (by x2?), we can't normalize absorption to an invariant quantity. Thus, it's difficult to corroborate models of optical transformation.

different sources, different optics

2 types of vehicles





A "nice" engine:
small particles "look" like the BC that's in the models, larger particles appear less pure

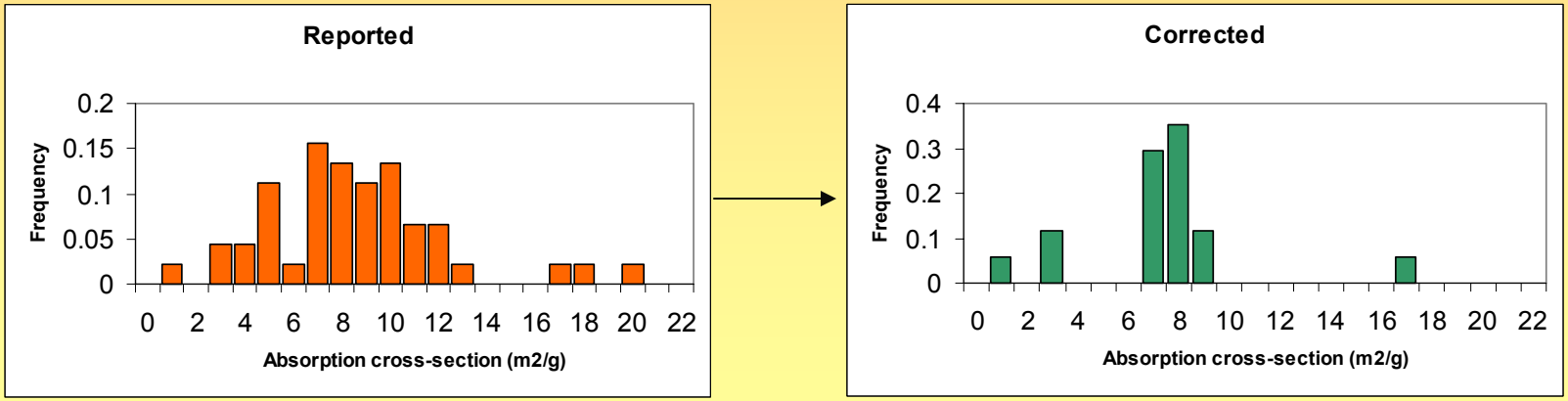
A "yucky" engine:
much larger particles

resolution & challenge

For fresh light-absorbing carbon,

- we think we can explain
  - many variations in refractive index
  - variations in mass absorption cross-section
- ...and yet,
  - "best guess" refractive index + theory doesn't match "best-guess" absorption cross-section

[Bond & Bergstrom, LAC investigative review, on verge of submission]



rephrased question

*"What are the limits in our ability to predict **the total forcing by aerosols** from individual source types?"*

BC-OC and direct-indirect balances matter.

We need a clear identification of relevant factors. Optical properties and size are two of them. However, there are others.

Don't overestimate the present sophistication of global models. "In-situ" measurements are well ahead of the measurement-model link.

Tami's top 4 *for this problem*

- Identify the invariant strongly light-absorbing quantity (and a method of measuring it)
- Statistical characterization of small-source populations (e.g. vehicles)
- Measured closure of optical and cloud-relevant properties from model variables, on fresh and transformed/transforming aerosol systems
- Identify key sensitive properties for determining direct & indirect forcing (from models)
  - iterate with inventories & ambient measurements
  - use urban/regional models to identify initial processing